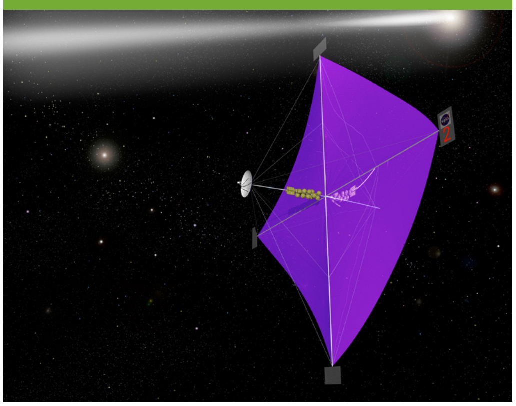
National Aeronautics and Space Administration

Vehicle Health

Solar Sail Contouring

NASA Marshall Space Flight Center



Solar sails are low-cost, efficient, in-space propulsion systems that use photons from the Sun to transport spacecraft on interplanetary journeys. Monitoring solar sail health during deployment and operations is critical to the integrity of the mission. Digital imaging systems must be able to observe different parts of a solar sail and identify wrinkles, folds, or other problems that reduce the sail's ability to optimally reflect sunlight and produce thrust. Creating contrasting visual location indicators on a sail is difficult because blinding sunlight bounces off the sail's mirror-like surface, making indicators hard to discern. Previously tested adhesive disks were observable but added unwanted mass and damaged thin sail material.

Task Description

This investigation tested three processes—**anodizing, coating, and embossing**—for applying visual location indicators on sail-like material while

1. Minimizing added mass
2. Bonding strongly to the sail
3. Providing adequate contrast to the sail material over appreciable viewing angles
4. Preventing alterations to the sail material that would affect its ability to produce thrust.

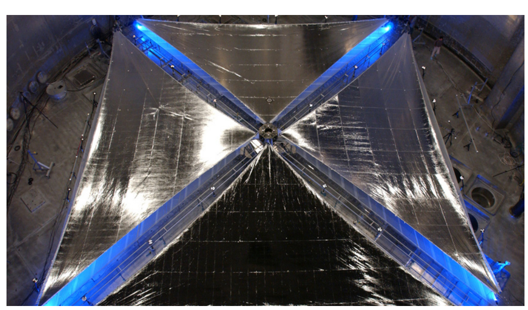
This Advanced Materials for Exploration (AME) 3-month feasibility study was completed in December 2004.

Results

The application methods were tested on 3-micron-thick multilayer insulation samples made of aluminum on Mylar™, a material similar to sail material. Marking techniques and materials were evaluated for their ability to make observable images that showed contrast between the original material and the marked areas, and researchers noted alterations created by the application process.

Spectral reflectance tests were performed on some samples by researchers from the Marshall Space Flight Center (MSFC) Space Environmental Effects Team. Measurements indicated that it may be possible to produce selective interference effects by anodizing or embossing the film and modifying its thickness so that it strongly reflects degrading ultraviolet light and transmits visible light. Viewing such transmitted light areas against a darker background, such as the back side of the sail, may be the best solution.

All three techniques added identification locators that contrasted with the material and were observable by a digital camera. The embossing technique showed the most promise for marking a sail without causing negative changes to material properties—with the bonus of adding



The mirror-like solar sail material maximizes reflection of solar photons but also reflects bright, blinding light that makes it difficult to monitor the sail's shape and condition. Location indicators that either reflect or transmit light and can be imaged by digital systems may solve this problem.

advanced materials for exploration

SOLAR SAIL CONTOURING

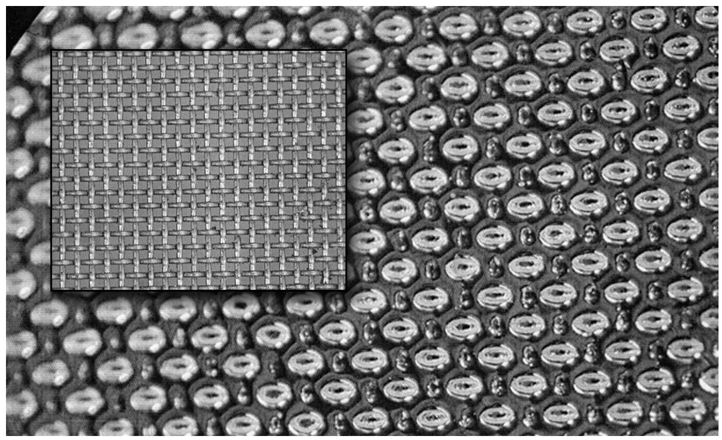
Method	Advantages	Disadvantages	Rating
Embossing: physically changed material by producing arrays of impressions and depressions	• Adds no mass or new materials that could alter sail properties • Easily applied • Provides partial spectral reflection	• Strained material beyond elastic limits	1
Anodizing: chemically changed material by adding film of aluminum oxide and adjusting thickness to produce interference colors	• Transparent, tough, thin, low mass • Appears black on shiny surface • Easily applied • Strongly bonded	• No strong interference patterns • Transparent windows transmit damaging ultraviolet light	2
Coating: added coating of highly reflective silicon nitride to aluminized polymer similar to back side of sail	• Strong, protective layer of film with low mass • Strongly bonded • Reduced reflectance • Increased emissivity	• Permanently altered sail material • Some mass added • Not all interference effects necessarily good	3

no weight and no new material to a sail. However, it locally strained the study material beyond its elastic limit, so application refinements and strength testing would be required to more thoroughly characterize this process on real sail material.

Potential Future Activities

All three application methods should be tested on actual sail materials being developed by NASA (3-micron Al-CP-1 and 2-micron Al-Mylar™-Cr films). Optical measurements should be made to compare the reflectivity of the location indicator markings and the sail material as a function of wavelength. The Marshall Center has test facilities and experts for producing the samples, making the spectral measurements, performing tensile testing, and creating a simulated space environment. This task identified embossing as the highest priority for future studies that should

1. Identify the optimum pattern and size for the embossed hemispheres, by rapidly producing a variety of embossed samples using a new laser-etching machine (delivered to the Marshall Center in 2005) that can produce locator hemispheres smaller than 5 microns in diameter; measure reflectivity and spectral intensity of samples
2. Ensure embossing does not affect sail material by testing tensile strength of samples and thermal properties
3. Test the embossed samples in a simulated space environment with a collimated light source that mimics the Sun
4. Test and compare embossing on the front and back of sail material.



Photomicrograph of a 250 x 250 mesh screen (inset) used as a die to produce embossing patterns, which show a shape imaged in the center of each embossed bump. Machined dies were used, with less success, to emboss patterns in sail-like material. Laser etching machines could be used on future experiments to produce smaller, more precise patterns.

Capability Readiness Level (CRL)

This AME task, using small coupons of solar sail-like material, tested three possible techniques for marking solar sails, with embossing showing clear advantages (CRL 2). Further testing with real solar sail material in the laboratory and later in a simulated environment would elevate this materials process to a CRL of 4 or 5. Elevation of this sail health monitoring capability is crucial to the success of solar sail missions.

Principal Investigator
Palmer Peters, retired NASA/MSFC

AME Contact/Project Lead
Beth Cook, NASA/MSFC, Beth.Cook@nasa.gov, (256) 544-2545

National Aeronautics and Space Administration

Marshall Space Flight Center
Huntsville, AL 35812

www.nasa.gov

NP-2006-03-32-MSFC